NASA TECH BRIEF

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Large Boron—Epoxy Filament-Wound Pressure Vessels

A propulsion motor of the type used to inject satellites into orbit can be viewed as a large pressure vessel which encloses a solid propellant grain; when the motor is activated, gases liberated by controlled combustion of the propellant pressurize the vessel and issue from a nozzle to provide thrust. Originally, pressure vessels (usually called chambers) were made of metal, at first of Type 410 chromium steel and later, because of increased operation requirements, of a titanium alloy. Unfortunately, metals have coefficients of expansion which differ substantially from those of propellant grains, and the difference gives rise to many problems, the most serious of which is separation of grains from the metal walls against which they were cast. To minimize problems arising from differences in expansion, a rubbery coating or liner is bonded to the interior surfaces of a motor chamber and to the propellant grain.

A chamber is designed to withstand the expected maximum gas pressure resulting from burning of the grain. Because weight is an important consideration, wall thicknesses are carefully calculated to provide a safety factor of only 1.2, but since the gas pressure developed in the chamber is controlled by the burning area of the propellant grain, it is evident that catastrophic failure of the motor can occur when the burning area is increased by a detachment of the propellant grain from the chamber walls.

A number of NASA research programs have been initiated to advance the state of the art in fabrication of motor chambers. Some of the programs have been involved with the development of liners, and some with the refinement of chamber-forming techniques, especially as required by novel alloys. For example, experiments with chambers fabricated from composites of glass fibers and epoxy have demonstrated the general applicability of filament-winding techniques, but of extreme importance are the results of programs which led to the development of the lightweight, highly efficient propulsion motor (titanium alloy chamber) used to orbit an Application Technology Satellite (ATS).

The highly successful performance of the titanium alloy ATS chamber prompted a new series of programs designed to advance the state of the art by use of advanced composite materials for fabrication of motor chambers, inasmuch as materials of this kind readily form firm bonds with propellant grains, and experiments with filament-wound structures had demonstrated the possibility of fabricating strong, lightweight chambers. Attention was quickly focused on advanced filamentary composites consisting of a reinforcing filament of boron or graphite in an epoxy resin matrix; composites of this kind have overall strengths approaching or exceeding known strengths of most metals. Filament-wound glass fiber—epoxy composites have, of course, been used to fabricate motor chambers, but the inherent large elasticity of the glass fibers overruled use of these materials for satellite motors. Boron— and graphite—epoxy composite materials have moduli of elasticity almost equal to or better than titanium and at least three times as high as glass fiber—epoxy materials; accordingly, the advanced composites can withstand strain (stretching) far better than the glass fiber composites.

The advanced composite material used to fabricate a pressure vessel (which was found to be competitive with the ATS chamber) is a prepreg (partially cured)

(continued overleaf)

consisting of 27 continuous, parallel boron filaments in an epoxy resin matrix arranged to form a tape approximately 3.2 mm (⅛ in) wide and 0.13 mm (0.0005 in) thick. A single continuous boron filament has a diameter of about 1 mm (0.004 in). In order to fabricate the chamber, the tape is wound on a form which must be removable after the composite has been cured.

Ordinarily, in a development program, a mandrel is fabricated nominally in the desired shape of the vessel, and prepreg tapes or filaments are wound in accordance with a pattern dictated by experience, by conjecture, or by preliminary stress analysis. Then, prototype tanks are tested to determine failure modes and the new data are laboriously incorporated in the design of new mandrels. Thus, by laborious and expensive effort, a final design is achieved. In contrast with prior procedures for designing filament-wound chambers, the configuration of the boron–epoxy composite pressure vessel was determined by a computer program (COMTANK). In this program, netting analysis theory is utilized together with the assumption that the filaments carry all the load and the matrix material serves only to hold the filaments to the vessel shape. In the design phase, the program computes such features as the required filament wrap angles and the wall thicknesses which are later used to generate the orthotropic material properties needed for the analysis phase. After design, the program provides an analysis of the proposed structure by viewing the chamber as a laminated orthotropic shell of revolution in which the stress-carrying ability of the matrix is included; the analysis is accomplished by developing a finite-element mathematical model of the chamber. A series of subprograms are included to compute geometric and composite material property data as required.

The actual chamber was fabricated from boron–epoxy prepreg layed on a mandrel of the shape dictated by the computer analysis. Planar wraps encompassed two titanium bosses of different diameters in the center of the end domes; the dome coordinates were optimized by the computer to eliminate high stress concentrations in the laminated composite layers.

An experimental boron–epoxy motor chamber was pressurized to destruction; the burst pressure, 264 N/cm^2 (383 psig), was 57.2 N/cm^2 (83 psig) above the ultimate design strength and exceeded the predicted burst strength of 231 N/cm^2 (335 psig).

Note:

Requests for further information may be directed to:

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Patent status:

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